J Technol Transfer (2008) 33:504–533
DOI 10.1007/s10961-007-9061-z

Do specific forms of university-industry knowledge transfer have different impacts on the performance of private enterprises? An empirical analysis based on Swiss firm data

Spyros Arvanitis · Nora Sydow · Martin Woerter

Published online: 8 September 2007

Abstract This study investigates the impact of a wide spectrum of Knowledge and Technology Transfer (KTT) activities (educational and research activities, activities related with technical infrastructure, and consulting) on two innovation indicators (a) in the framework of an innovation equation with variables for specific forms of KTT activities as additional determinants of innovation, and (b) based on a matched-pairs analysis for several specific forms of KTT activities. The data used in the study were collected by means of a survey of Swiss enterprises that took place at the beginning of 2005. We found that research and educational activities improve the innovation performance of firms in terms of sales of considerably modified products, research activities in addition also in terms of sales of new products. This could be shown by several methods: the innovation equation approach with instrument variables for specific forms of KTT activities as well as two matching methods.

Keywords Knowledge and technology transfer · Innovation activities · R&D activities

JEL Classification O30

1 Introduction and plan of the study

The topic "knowledge and technology transfer" has spurred great interest among academic researchers and policy-makers since many years. The interaction of business sector and

S. Arvanitis (✉) · N. Sydow · M. Woerter
KOF Swiss Economic Institute, ETH Zurich, Zurich 8092, Switzerland
e-mail: arvanitis@kof.ethz.ch

N. Sydow
e-mail: sydow@kof.ethz.ch

M. Woerter
e-mail: woerter@kof.ethz.ch

science institutions through the exchange of knowledge and technology has become a central concern not only for applied economics but also for economic policy in the last years.[1] In a knowledge economy, science is exerting an increasingly large influence on innovation, especially in fast-growing knowledge-intensive industries. Thus, the extent and intensity of industry-science relationships is considered to be a major factor contributing to high innovation performance, either at the firm-level, industry-level or country-level (see OECD 2002).

Experiences of the USA suggest that research excellence of publicly financed science institutions and commercialization of research results by private enterprises are compatible goals which reinforce each other, if both sides adopt a long-term perspective (as e.g. in aerospace, computers and telecommunication). However, there is accumulating evidence that many OECD countries are lagging behind in terms of KTT. The interface between business firms and science institutions, especially universities, has to be improved and as a consequence knowledge and technology transfer activities have to be intensified. Also in Switzerland it is asserted by many observers that the industry-science interface is far from being satisfactory (see e.g. Zinkl and Huber 2003).

Particularly in the view of policy-makers an intensive exchange of knowledge is not a goal by itself but a means to seizable economic benefits. Measuring the impacts of transferred knowledge and technology is a methodological challenge for economists because the impacts are usually numerous and they are almost always difficult to separate from other parts of firm activities. In many instances, determining the meaning of knowledge transfer "effectiveness" proves to be a difficult task.[2] In order to be able to check the robustness of our results we choose a multiple approach, using both parametric and semi-parametric econometric methods.

This study investigates the impacts of a spectrum of Knowledge and Technology Transfer (KTT) activities (general information, educational and research activities, activities related with technical infrastructure, and consulting) on several innovation indicators (a) in the framework of an innovation equation with variables for specific *forms* of KTT activities as additional determinants of innovation, and (b) based on a matched-pairs analysis for several specific *forms* of KTT activities. A specific aim of the paper is to identify differences among specific forms of KTT activities with respect to their impact on a firm's innovation performance. The data used in the study were collected by means of a survey of Swiss enterprises that took place at the beginning of 2005.

New elements of the analysis are: (a) the differentiated measurement of a wide spectrum of KTT activities covering 19 single forms of KTT activities; (b) the use of alternative methods for estimating the impact of KTT activities on innovation performance (matched-pairs analysis, innovation equations); (c) the wide coverage of industries and firm size classes. This is the first study on this topic for the Swiss economy.

In Sect. 2 we present a summary of empirical literature. Section 3 deals with the data used in this study. In Sect. 4 data on the several forms of KTT activities taken into

---

[1] *Economics*: see e.g. volume 34, issue 3 of *Research Policy* of April 2005 (edited by A.N. Link and D.S. Siegel) dedicated to "University-based Technology Initiatives"; "Academic Science and Entrepreneurship" (edited by A. Jaffe, J. Lerner, S. Stern and M. Thursby), forthcoming in the *Journal of Economic Behaviour and Organization*; volume 28, issue 3–4 of the *Journal of Technology Transfer* of August 2003 devoted to the "Symposium on the State of the Science and Practice of Technology Transfer". *Policy*: see e.g. OECD (2003), OECD (2002) and OECD (1999).

[2] See e.g. Bozeman 2000; Georghiou and Roessner (2000) for recent reviews of the central issues related to this question; for reviews of the related econometric issues see e.g. Klette et al. (2000); Hall and Van Reenen (2000).

consideration in this study are presented. In Sect. 5 we introduce a simple model of innovation performance and test the hypothesis of specific KTT activities correlating positively with innovation performance measured e.g. by the sales share of new products. In a further step we investigate in Sect. 6 the same hypothesis in a different setting by comparing the innovation performance between firms with and firms without specific types of KTT activities with the help of matched-pairs analysis based on two different matching methods. Finally, Sect. 7 contains a summary and some conclusions.

2 Summary of empirical literature

We concentrate here on empirical studies investigating the impact of KTT activities on the innovation performance at firm level based on *direct* measures of KTT activities emphasizing formal R&D co-operation and/or the intensive use of university knowledge as external knowledge source via publications, educational activities etc. (10 studies; Table 1). The main criterion for the choice of the studies reported in the Table 1 was that the studies should be based on firm-level data.[3]

Most of the studies that are based on direct measures of KTT activities, primarily R&D co-operation and/or intensive use of university knowledge as an external knowledge source, found a positive effect of KTT activities on different measures of innovation such as the propensity of registering an innovation for patenting, the number of patents applications, the R&D intensity, the introduction of product and/or process innovations as well as the sales share of innovative products. This was particularly the case for R&D co-operation in European countries (Germany, France, Sweden). However, a study dealing with projects supported by the Advanced Technology Programme (ATP) in the USA could not find any significant effect of university participation in such projects on the generation of new technology applications. Moreover, university participation showed even a negative effect on the expectation of commercialization of new inventions.

On the whole, the results are indicative but not completely comparable because some of the observed differences can be traced back to differences with respect to the sectors and industries covered in the studies, the specification of the variables of KTT activities and the nature of the investigations (cross-sectional versus longitudinal approach).

3 Data

The data used in this study were collected in the course of a survey of Swiss firms that yielded data on the incidence of KTT activities, on forms, channels, motives and impediments of the KTT activities as well on some basic firm characteristics (innovation and R&D activities, investment, sales, exports, employment and employees' vocational education).[4] The survey was based on a (with respect to firm size) disproportionately stratified random sample of firms with at least five employees covering all relevant industries of the manufacturing sector, the construction sector and selected service industries (excluding industries with an expected very low propensity of KTT activities such hotels/catering,

[3] For recent studies on the impact of public R&D expenditure on business R&D at country or sector level see e.g. Guellec and van Pottelsberghe de la Potterie (2003) (17 OECD countries); Bönte (2004) (West German manufacturing industries).

[4] Versions of the questionnaire in German, French and Italian are available in http://www.kof.ethz.ch.

Table 1 Impact on KTT activities on innovation performance; studies based on *direct* measures of KTT activities

Study	Impact variable	Data/KTT activities	Impact
Nelson (1986)	R&D intensity	Data from the Yale survey for enterprises in 130 US industries 1984; assessment of the relevance of various fields of university research for a firm's own R&D activities	University research contributes positively and significantly to R&D intensity of the industry in question
Mansfield (1991, 1998)	Percentages of new products and processes; percentages of new	Sample of 76 major US firms in seven industries for 1975–1985; sample of 77 major firms in seven industries) for 1986–1994	Similar results for both periods: about 10% of the new products and processes introduced in these industries could not have been developed (without substantial delay) in the absence of recent academic research.
			Time-lag between academic research results and first commercial introduction of new products/ processes was smaller in the second period
Beise and Stahl (1999)	Firms were asked whether any of the innovations could not have been developed or only with a delay of at least 1 year in the absent of recent research at universities and other public research institutions; share of sales of new products which could not have been developed without university research	Data from Mannheim Innovation Panel for 2,500 German manufacturing firms	Public research has a considerable effect on industrial innovations. A considerable share of companies has identified product and process innovations which would not have been developed without recent research of public research institutions. Geographical proximity is not important for Germany

Table 1 continued

Study	Impact variable	Data/KTT activities	Impact
Kaufmann and Tödtling (2001)	Products new to the market/products new for the firm only	Data from the REGIS survey 1996 for firms from several European regions; assessment of the relevance of several types of external innovation partners (customers, suppliers, consultants, technology transfer offices, contract research organisations and universities) for a firm's innovation activities	Firms cooperating with science increase their ability to realise more radical innovations and to introduce products which are new to the market. Universities are not important for incremental innovations
Adams et al. (2003)	Patents, laboratory R&D budget, company financed laboratory R&D budget, federally funded laboratory R&D budget, expenditures on federal laboratory R&D	Data from (a) survey of industrial laboratories (200 US companies from chemicals, machinery, electrical equipment, and motor vehicle industries; 1996–1997); (b) survey collecting data on intramural R&D carried out in federally funded laboratories—the same that are cited by the industrial laboratories in the 1996–1997 survey. KTT activities: government contractor (yes/no); collaborative R&D (yes/no)	Co-operative research and development agreements (CRADAs) have stimulated industrial patents and company-financed R&D. No other channel of technology transfer yielded a comparable effect

Table 1 continued

Study	Impact variable	Data/KTT activities	Impact
Becker (2003)	Innovation input indicators: R&D expenditures intensity, R&D labour intensity; innovation output indicators: introduction of product innovations, introduction of process innovation	Data from the Mannheim Innovation Panel Survey for 1,584 German manufacturing firms; assessment of the importance of several external knowledge sources	Input indicators: university research as a knowledge source and/or R&D co-operation with universities show a stimulating effect on the level of in-house R&D. Output indicators: university knowledge as an external knowledge source has no stimulating effect on product innovations. In contrast, joint R&D with universities do have a stimulating effect. Process innovations are positively influenced by university knowledge and R&D co-operation with universities
Hall et al. (2003)	Development and commercialization of new technology applications	Data for 352 projects founded by the Advanced Technology Programme (ATP) in the period 1991–1997; three types of university involvement	University participation showed no effect on the generation of new technology applications and a negative effect on the expectation of early commercialization
Monjon and Waelbroeck (2003)	Introduction of product innovations; introduction of process innovations; degrees of novelty of product innovations (incremental, radical product innovations)	Data from the Community Innovation Survey, the '*Enquête Annuelle d'Entreprises*', and the '*Enquête Annuelle d'Entreprises par fractions*' for about 3,200 French enterprises; formal R&D co-operations; universities and public research institutions as important knowledge sources	Firms benefit from formal international collaboration with universities and public research institutions

Table 1 continued

Study	Impact variable	Data/KTT activities	Impact
Fritsch and Franke (2004)	Propensity to register innovations for patenting; number of innovations registered for patenting	Data from a survey in three German regions (Baden, Hanover-Brunswick-Goettingen, Saxony) comprising all enterprises with 10 or more employees (1,800 firms); co-operation with public research institutions (yes/no); external funds attracted by public research institutions	The indicator for R&D co-operations with public research institutions as well as the logarithm of external funds attracted by public research institutions impact positively the propensity to register at least one innovation for patenting but not the number of innovations registered for patenting
Lööf and Broström (2005)	Expenditures on R&D, patents applications, sales share of new products	Data from the Community Innovation Survey for Sweden for the period 1998–2000 for 790 firms (after the elimination of low-R&D sectors and all firms without R&D or other innovation expenditures)	A comparison of R&D collaborating with non-collaborating firms based on a matched-pairs analysis showed that in the case of collaborating firms knowledge diffusion from academic research contributed to an increase in total R&D expenditures. Furthermore collaborating firms showed a greater R&D productivity in terms of sales of innovative products and patent applications

retail trade, real estate/leasing, personal services) as well as firm size classes (on the whole 25 industries and within each industry three industry-specific firm size classes with full coverage of the upper class of large firms). Valid answers were received from 2,582 firms, i.e. 45.4% of the firms in the underlying sample. The response rates do not vary much across industries and size classes with a few exceptions (over-representation of wood processing, energy industry and machinery, under-representation of clothing/leather industry). The non-response analysis (based on a follow-up survey of a sample of the non-respondents) did not indicate any serious selectivity bias with respect to the incidence of KTT activities with science institutions. About 671 firms reported KTT activities of various types (26.0%). These firms were used in this analysis (see Table A.1 in the appendix for the composition of used data set by industry and firm size). The fact that we used only a subset of the original sample may raise the question of a possible sample selectivity bias. This issue was pursued in another study (see Arvanitis et al. 2005). The estimates of a Heckman selectivity model (dependent variable of the selectivity equation: overall KTT-activities yes/no; (alternatively) dependent variables of the censored equation: four specific forms of KTT-activities as defined in this study) showed no correlation between the selectivity and the censored equation. So we refrained in this study from corrections for selectivity bias as it is not necessary. We also refrained from substituting for missing values due to item non-response.

4 Forms of KTT activities: descriptive analysis and construction of the KTT variables for the econometric analysis

The KTT-active firms were asked to evaluate the importance of 19 different single forms of KTT activities on a five-point Likert scale ranging from 1 ("not important") to 5 ("very important"). These 19 single forms were classified in five categories: informal informational activities, educational activities, activities related to technical infrastructure, research activities and consulting (see Table 2).

"Tacit" forms of KTT were more important than "codified" ones. More than 50% of KTT-active firms in Switzerland found (a) informal, personal contacts that aim at gaining some general information on technological opportunities and/or (b) a wide spectrum of educational activities as the most important forms of KTT activities (see row 1 and 8 in Table 2). Between 12% and 18% aimed primarily at utilizing research activities, activities related to technical infrastructure and consulting activities (see row 5, 18 and 22 in Table 2).

At a more detailed level, firms reported "reading of and referring to publications" (33.1% of KTT-active firms), "attending conferences and workshops" (30.4%) and "informal contacts" (30.4%) as the most important single KTT activities (see Table 2). Other important activities were "attending university training courses by firm employees" (22.1%), and "employing graduates in R&D" (18.4%). Among educational activities writing diploma theses on a subject of special interest for a firm was also of a certain importance (15.7%). Finally, co-operation in R&D was very important for 16.3% of KTT-active firms.

In fact, KTT-active firms combined different forms of KTT. High-tech firms as well as firms in the knowledge-based services and in construction most frequently combined two main groups of forms, namely informal informational and educational activities.

We constructed four dichotomous variables for the KTT activities, one for each of four of the five categories distinguished in the descriptive analysis: (a) utilization of educational

Table 2 Forms of KTT activities

KTT main forms/single forms	Percentage of KTT-active firms reporting 4 or 5 on a five-point Likert scale (1: 'not important'; 5: 'very important')
Informal(variable INFO)[a]	56.6
Informal contacts	30.4
Attending conferences	30.4
Reading of, referring to publications	33.1
Technical infrastructure (variable INFR)[a]	11.9
Common laboratory	3.9
Use of university technical infrastructure	10.7
Education (variable EDUC)[a]	52.3
Employing graduates in R&D	18.4
Contacts with university of graduates employed in R&D	10.1
Students' participation in firm R&D	10.9
Joint diploma theses	15.7
Joint PhDs	7.0
University researchers' participation in firm R&D	10.1
Common courses	3.8
Teaching of firm researchers at the university	7.7
Attending university training courses	22.1
Research (variable REAS)[a]	17.8
Joint R&D projects	16.3
Long-term research contracts	5.0
Research consortium	4.1
Consulting (variable CONS)[a]	15.3
Expertise	11.1
Consulting	13.8
N	671

Note: [a] Percentage of firms reporting a value 4 or 5 on a five-point Likert scale (1: not important'; 5: 'very important') at least in one of the single forms belonging to the corresponding main category of forms of KTT activities

activities (variable EDUC: 1: firms reporting 4 or 5 on a five-point Likert scale with respect to at least one out of nine single forms of educational activities; 0: all other KTT-active firms); (b) utilization of research activities (variable REAS: 1: firms reporting 4 or 5 on a five-point Likert scale with respect to at least one out of three single forms of research activities; 0: all other KTT-active firms); (c): utilization of university technical facilities (variable INFR: 1: firms reporting 4 or 5 on a five-point Likert scale with respect to at least one out of two single forms of infrastructure-oriented activities; 0: all other KTT-active firms); (d): use of consulting (variable CONS: 1: firms reporting 4 or 5 on a five-point Likert scale with respect to at least one out of two single forms of research activities; 0: all other KTT-active firms). We did not construct a variable for informal contacts of general informational character because these build very often the background for the other four types of activities.

5 Impact of KTT activities on innovation performance I: a model of innovation and technology transfer

5.1 Conceptual background and main hypothesis, model specification and estimation method

5.1.1 Conceptual background and main hypothesis

Our main hypothesis is that KTT activities would improve the innovation performance of firms. This KTT effect could be traced back to an increase of technological opportunities anticipated by firms due to university-industry knowledge transfer. This would include effects from a wide palette of KTT activities such as exchanging scientific and technical information, various educational activities (e.g. recruitment of R&D personnel from the universities, joint PhDs, specialized training courses), consulting, use of technical infrastructure, and, of course, co-operation in research. The prominent role of technological opportunities as a major supply-side determinant of innovation is often emphasized in literature (see e.g. Klevorick et al. 1995; for the empirical relevance of technological opportunities for US firms; for Swiss firms see Arvanitis and Hollenstein 1996). We do not have a priori any specific hypotheses with respect to different impacts of different forms of KTT activities. In the literature joint R&D is emphasized; it is mostly the only type of interaction between universities and firms that is taken into consideration. We expect to find empirically some answers to this question.

For the specification of the innovation equation we build on the "resource-based" view of firms' behaviour (see e.g. Barney et al. 2001). The resource endowment of the firm with respect to physical and human capital is besides firm size the most important determinant of innovation performance taken into consideration in our model.

Finally, for the specification of the determinants of the four types of KTT-activities measured by the variables REAS, EDUC, CONS and INFR respectively we used the model developed in Arvanitis et al. (2005).

5.1.2 Model specification

The equations for the two innovation variables, the logarithm of the sales share of new products (LNEWS) and the logarithm of the sales share of significantly modified already existing products (LIMPS), contained as independent variables proxies for the intensity of human capital (LQUAL; logarithm of the share of employees with tertiary-level education), the intensity of physical capital (LCI: gross investment per employee), the affiliation of the firm (FOREIGN; foreign firm yes/no), and control variables for firm size (6 dummy variables) and sector (4 dummy variables). According to standard empirical evidence from earlier studies we expected positive effects for LQUAL, LCI and the firm size. Finally, we included alternatively the four dichotomous variables for the KTT activities (EDUC, REAS, INFR, CONS) as defined in Sect. 4. The effect of the variable FOREIGN was not a priori clear. In sum, the *innovation equations* were specified as follows:

$$
\begin{aligned}(LNEWS; LIMPS) = f[&LC, LQUAL, FOREIGN, (EDUC; REAS; CONS; INFR),\\ &firmsizedummies, controlsforsectors]\end{aligned} \tag{1}
$$

(LNEWS and LIMPS were used alternatively as dependent variables, EDUC, REAS, CONS, INFR were used alternatively as independent variables in Eq. 1.

However, being involved in KTT activities is not exogenous to innovation activities. Innovative firms have a tendency to acquire external knowledge, particularly science-based knowledge, to complement the in-house generated know-how. We accounted for this endogeneity effect by estimating an instrument variables version of each innovation equation for every specific type of KTT activities (EDUC, REAS, INFR, CONS). As instruments were used a series of firm characteristics which are relevant for KTT activities but do not correlate strongly with the innovation variables, at least one of them does not correlate at all either with the innovation variables or the residuals of the innovation equations. These were the export intensity (logarithm of exports as a share of sales; LEXP), the firm age (logarithm of firm age; LAGE), variables for five groups of obstacles of KTT activities constructed through a principal component factor analysis of 26 single obstacles (OBSTACLE1– OBSTACLE5), variables for four groups of motives of KTT activities constructed through a principal component factor analysis of 20 single motives (MOTIVE1–MOTIVE4) and dummy variables for the geographical location (see Arvanitis et al. 2005 for the motivation for this specification and details for the construction of the variables). In sum, the *equations for the specific forms of KTT activities* are specified as follows:

$$(EDUC; REAS; CONS; INFR) = g[LEXP, LAGE, MOTIVE1 - MOTIVE4, OBSTACLE1 - OBSTACLE5, controls] \tag{2}$$

(EDUC, REAS, CONS, INFR were used alternatively as dependent variables in Eq. 2)).

5.1.3 Estimation method

We used a two-step procedure. In a first step we estimated probit models for all four variables for KTT activities (see Table A.2 in the appendix for the estimates). Based on the parameters of these models we obtained estimates for EDUC, REAS, INFR and CONS respectively that were then inserted alternatively as instrument variables in the innovation equations. The two dependent variables being truncated at zero because of the portion of firms with zero sales, we used the tobit procedure to estimate both innovation equations. We avoided sample selection bias by taking account also of the firms with zero sales of new products or sales of strongly modified products.

5.2 Results

Table 3 shows the tobit estimates for the two dependent variables (LNEWS, LIMPRS) with REAS and EDUC instrumented respectively (see Table A.4 in the appendix for the descriptive statistics and Table A.5 for the correlation matrix). As already mentioned, in a first step we estimated probit models for all four variables for KTT activities (see Table A.2 in the appendix for the estimates). We refrain here from commenting on these estimates that were only used for the instrumentation of the variables for the specific types of KTT activities (see Arvanitis et al. 2005 for a thorough discussion of these results).

The two variables reflecting the firms' resource endowment (LQUAL and LCI) have the expected positive signs in all four estimates but they are statistically significant (at the 10%

Table 3 Innovation performance and research and educational activities respectively (variables REAS, EDUC); tobit estimates

Explanatory variables	LNEWS[a]	LIMPS[b]	LNEWS[a]	LIMPS[b]
LQUAL[c]	0.186*(0.106)	0.053(0.120)	0.200*(0.106)	0.062(0.120)
LCI[d]	0.138**(0.061)	0.056(0.071)	0.135**(0.062)	0.052(0.071)
FOREIGN[e]	–0.141(0.189)	–0.044(0.217)	–0.080(0.190)	0.026(0.218)
REAS instrumented[f]	0.226***(0.053)	0.245***(0.061)		
EDUC instrumented[g]			0.213***(0.058)	0.244***(0.067)
Firm size				
20–49 employees	0.660**(0.299)	0.380(0.343)	0.675**(0.300)	0.408(0.343)
50–99 employees	0.467*(0.283)	0.784**(0.322)	0.464*(0.284)	0.789**(0.322)
100–199 employees	0.935***(0.289)	0.965***(0.330)	0.928***(0.291)	0.954***(0.331)
200–499 employees	0.795***(0.282)	0.868***(0.321)	0.750***(0.285)	0.821**(0.324)
500–999 employees	0.892**(0.350)	0.794**(0.399)	0.843**(0.355)	0.743*(0.403)
1,000 employees and more	0.849**(0.386)	1.066**(0.437)	0.831**(0.389)	1.037**(0.440)
High-tech manufacturing[h]	1.216***(0.377)	1.245***(0.423)	1.376***(0.375)	1.409***(0.419)
Low-tech manufacturing[i]	0.803**(0.384)	0.229(0.432)	0.903**(0.384)	0.332(0.430)
Knowledge-based services[j]	0.027(0.409)	0.294(0.459)	–0.088(0.416)	0.169(0.458)
Traditional services[k]	0.933**(0.437)	0.290(0.496)	0.922**(0.433)	0.279(0.496)
Constant	–1.444*(0.787)	–0.042(0.889)	–2.080***(0.767)	–0.718***(0.863)
N	588	588	588	588
N(left-censored)	178	188	178	188
Pseudo R^2	0.053	0.048	0.046	0.046
LR statistics (χ^2)	105***	97***	93***	95***

Note: [a] LNEWS: logarithm of the sales share of new products; *b* LIMPS: logarithm of the sales share of significantly modified already existing products; [c] LQUAL: logarithm of the share of employees with tertiary-level vocational education 2004 (universities, universities of applied sciences, other business and technical schools at tertiary level); [d] LCI: logarithm of gross investment per employee 2004; [e] FOREIGN: dummy variable for foreign firms; [f] REAS instrumented: see Table A.2 in the appendix for the instrument equation for REAS; [g, h] EDUC instrumented: see Table A.2 in the appendix for the instrument equation for EDUC; dummy variable for high-tech manufacturing: chemicals, plastics, machinery, electrical machinery, electronics, instruments and vehicles; [i] dummy variable for low-tech manufacturing: all other manufacturing industries; [j] dummy variable for knowledge-based services: banks, computer services, business services; [k] dummy variable for traditional services: wholesale trade, transportation; reference sector: construction; 6 dummy variables for firm size; reference firm size class: 5–19 employees; ***, **, * denote statistical significance at the 1, 5 and 10% test level and 5% level respectively) only in the estimates for LNEWS (columns 1 and 3 in Table 3). The estimated coefficient of the human capital intensity is somewhat larger than that of capital intensity in both estimates for LNEWS indicating the particular importance of human capital in the innovation process. Seemingly, it does not make a difference if the firm is domestic or foreign.

The variables EDUC and REAS show the expected positive sign and are highly significant in all four estimates of the innovation equation (NEWS, LIMPS) (column 1–4). This is an important result emphasizing the relevance of educational as well as research activities in co-operation with science institutions for a firm's innovation performance. Finally, firm size is positively correlated with the innovation variables quite in accordance with standard empirical results of earlier studies.[5]

Table 4 contains the tobit estimates for the two dependent variables (LNEWS, LIMPS) with INFR and CONS instrumented respectively. Positive effects for LQUAL and LCI were also found in these estimates but only those for LNEWS were statistically significant at the 5% and 10% test level respectively (column 1 and 3). There is no significant effect for the variable FOREIGN also in the estimates in Table 4. Finally, there is also in this case a discernible positive size effect.

The variable INFR shows a positive and statistically significant effect only in the estimates for LNEWS (column 3). Thus, the utilization of university technical infrastructure seems to serve primarily to the development of new products. We could not find any statistically significant effect for consulting activities (column 1 and 2).

In sum, activities utilizing educational (variable EDUC) and research activities (variable REAS) seem to improve considerably the innovation performance of firms both in terms of sales of new products and sales of considerably modified products. No discernible differences could be found between these two most important categories of KTT activities with respect to the market-oriented innovation indicators used in this study. A positive impact was also found for activities related mainly to the utilization of university technical infrastructure (variable INFR) with respect to the sales of new but not of significantly modified products. No impact could be found for consulting activities (variable CONS).

Since the results are only cross-section estimates, it was not possible to test directly the existence of causal relations between the independent variables, particularly EDUC and REAS, and the dependent variables. Nevertheless, some robust regularities came out, which if interpreted in view of our main hypothesis could possibly indicate the direction of causal links.

6 Impact of KTT activities on innovation performance II: a matched-pairs analysis

6.1 Main hypothesis, model specification and method

6.1.1 Main hypothesis

Our main hypothesis is that KTT activities, particularly research projects and/or educational activities in co-operation with universities, would show on average a significantly higher innovation performance, measured through output innovation measures (sales share of new products or sales of considerably modified products) than "structural similar" firms

[5] Estimates based on an alternative specification of firm size with a linear and a quadratic term with respect to the number of employees showed a relationship of an inverse U-shape. This is in accordance with earlier findings; see e.g. Arvanitis (1997).

Table 4 Innovation performance and consulting and technical infrastructure-oriented activities respectively (variables CONS, INFR); tobit estimates

Explanatory variables	LNEWS[a]	LIMPS[b]	LNEWS[a]	LIMPS[b]
LQUAL[c]	0.263**(0.105)	0.136(0.118)	0.259**(0.105)	0.143(0.117)
LCI[d]	0.129**(0.060)	0.056(0.068)	0.132**(0.059)	0.057(0.068)
FOREIGN[e]	–0.032(0.188)	0.011(0.215)	–0.049(0.188)	0.013(0.215)
CONS instrumented[f]	–0.145(0.192)	0.225(0.216)		
INFR instrumented[g]			0.416**(0.187)	0.138(0.214)
Firm size				
20–49 employees	0.705**(0.300)	0.470(0.341)	0.771**(0.301)	0.480(0.342)
50–99 employees	0.494*(0.286)	0.822**(0.322)	0.543*(0.286)	0.833***(0.323)
100–199 employees	1.021***(0.289)	1.100***(0.327)	1.094***(0.289)	1.103***(0.328)
200–499 employees	0.890***(0.283)	0.939***(0.320)	0.915***(0.282)	0.952***(0.320)
500–999 employees	1.040***(0.351)	0.926** (0.397)	1.056***(0.349)	0.952**(0.397)
1,000 employees and more	1.036***(0.390)	1.253***(0.439)	1.112***(0.391)	1.285***(0.441)
High-tech manufacturing[h]	1.500***(0.368)	1.593***(0.409)	1.461***(0.368)	1.571***(0.410)
Low-tech manufacturing[i]	0.919** (0.380)	0.383(0.424)	0.920**(0.380)	0.383(0.424)
Knowledge-based services[j]	–0.019(0.406)	0.275(0.451)	0.049(0.406)	0.268(0.452)
Traditional services[k]	0.626(0.433)	0.051(0.488)	0.681(0.432)	0.044(0.488)
Constant	–2.153***(0.744)	–1.009(0.828)	–2.323***(0.747)	–1.026(0.831)
N	588	588	588	588
N(left-censored)	178	188	178	188
Pseudo R^2	0.044	0.041	0.046	0.041
LR statistics (χ^2)	88***	87***	92***	86***

Note: [a] LNEWS: logarithm of the sales share of new products; [b] LIMPS: logarithm of the sales share of significantly modified already existing products; [c] LQUAL: logarithm of the share of employees with tertiary-level vocational education 2004 (universities, universities of applied sciences, other business and technical schools at tertiary level); [d] LCI: logarithm of gross investment per employee 2004; [e] FOREIGN: dummy variable for foreign firms; [f] CONS instrumented: see Table A.2 in the appendix for the instrument equation for CONS; [g] INFR instrumented: see Table A.2 in the appendix for the instrument equation for INFR; [h] dummy variable for high-tech manufacturing: chemicals, plastics, machinery, electrical machinery, electronics, instruments and vehicles; [i] dummy variable for low-tech manufacturing: all other manufacturing industries; [j] dummy variable for knowledge-based services: banks, computer services, business services; [k] dummy variable for traditional services: wholesale trade, transportation; reference sector: construction; 6 dummy variables for firm size; reference firm size class: 5–19 employees; ***, **, * denote statistical significance at the 1, 5 and 10 test level without such activities. To show this we also used matched-pairs analysis which can be viewed as an alternative approach to the innovation model presented in the previous section.

6.1.2 Model specification and method

In order to measure appropriately the influence of a specific type of KTT activities ("treatment effect")[6] on a firm's innovation performance we should be able to measure the performance difference of the two "states" (involved/not involved in a certain type of KTT activities) of a firm, keeping all other things equal. Mostly only one of these two possible states observable: either is a firm involved *or* not involved in a certain type of KTT activities. Thus, the proper comparison of these states is in most cases not possible. Heckman et al. 1998 developed a methodology to approximate this non-observable ("counterfactual") state of a certain firm with the observable same state of another firm which is "structurally similar" to the first one according to a series of firm characteristics formally defined by a vector X. Thus, besides the group of firms which are KTT-active in a certain way (e.g. with respect to research or educational issues) we need a pool of firms which are not KTT-active in the same way (control group) out of which "structurally similar" firms are selected according to a "proximity" criterion. The comparison of the two states for KTT-active firms and firms which are not KTT-active with respect to a certain type of activities is performed by comparing the means of the innovation performance variables for the "treated" firms and the "twin" "non-treated" firms matched to the "treated" ones according to the proximity criterion that we apply here. The multi-dimensionality of the matching problem (matching with respect to each single element of vector X) can be reduced under certain conditions (see Rosenbaum and Rubin 1983) to a mono-dimensional (scalar) propensity score which comprehends the entire information of all relevant characteristics. If Y_{1i} is a vector of innovation measures for the treated firm i [$i \in (d = 1)$] and Y_{0i} the corresponding vector for a firm j belonging to the control group [$j \in (d = 0)$], which is the twin firm to firm i, then the performance difference between the two firms is defined as:

$$\Delta Y = Y_{1i} - Y_{0i} \tag{3}$$

In a *first* step we estimated the propensity scores P(X) by applying a probit model of the probability of a firm to get involved in a certain form of KTT activities (see Table A.3 in the appendix). We distinguished four types of KTT activities, which are described by the dichotomous variables REAS, INFR, CONS (see Sect. 4 for the construction details) and EDUC1 (1: firms reporting 4 or 5 on a five-point Likert scale with respect to at least one out of nine single forms of educational activities *and* taking the value 0 for the variable REAS; 0: all other KTT-active firms).[7]

As independent variables X we used variables for a firm's endowment (LQUAL; LCI), the degree of exposition to international competition (LEXP), firms' affiliation

[6] The expression "treatment effect" comes from the labour market research, where individuals are "treated" via a concrete policy measure. It is used here analogously for firms involved in KTT activities, even if this is not the result of any policy measure.

[7] Firms with a focus in educational activities *without* the additional restriction "taking the value 0 for the variable REAS" (as in variable EDUC in Sect 5) could not be matched because the number of available control firms in this case is considerably lower than the number of treated firms.

(FOREIGN), variables for five groups of impediments of KTT activities constructed through a principal component factor analysis of 26 single obstacles (OBSTACLE1–OBTACLE5), variables for four groups of motives for KTT activities also constructed through a principal component factor analysis of 20 single motives (MOTIVE1–MOTIVE4) and a series of dummy variables controlling for industry, firm size and geographical location (see Table A.3 in the appendix for more details and Arvanitis et al. 2005 for a discussion of the model specification used).

In a *second* step all firms were distributed to adjustment cells according to the quintiles of the estimated propensity scores. The search for a “twin” firm is then restricted only to the firms of the same adjustment cell, i.e. quintile of propensity scores.

In a *third* step the “structurally similar” firm inside an adjustment cell was identified for each treated firm. We used two different matching methods to identify the structurally similar firms out of the pool of the non-treated firms. According to the first method used, nearest neighbour matching, the “twin” firm j to firm is one fulfilling the condition:

$$min_i|P_i - \mathrm{P}_j| \tag{4}$$

whereas $\mathrm{P_i}$, $\mathrm{P_j}$ are propensity scores for the firms i and j respectively. The treated firm can have a higher or a lower propensity score than the non-treated one, therefore the absolute value of the difference of the two propensity scores has to be considered. The second method used in this study, caliper matching, is based on the same proximity measure as the nearest neighbour method which in this case is restricted up to a certain value ε (maximum admissible difference of the propensity scores):

$$|P_i - P_j| < \varepsilon \tag{5}$$

Different adjustment cells can have different ε values; the ε values are dependent on the distribution of the propensity scores inside an adjustment cell.

In a *fourth* and last step the means of the variables measuring innovation performance of the group of the treated firms and the group of the “twin” non-treated firms were compared by means of a two-tailed *t*-test for the difference of the means. We used two innovation variables: (1) sales of new products as a percentage of total sales; (2) sales of significantly improved or modified (already existing) products as a percentage of total sales.

6.2 Results

We discuss here the results based on two matching methods, neighbour matching and calliper matching (Tables 5–8). The findings are quite robust with respect to both methods. As an additional check we calculated the means of the covariates of the propensity scores estimates (see Table A.3 in the appendix) separately for the “treated” firms and the matched “non-treated” firms and tested the statistical significance of the difference of the means for each covariate by a two-tailed *t*-test. None of the differences was found to be statistical significant at the 5% test level.

Firms with primarily research co-operations with universities show on average a sales share of new products, which is about 35% higher than that of firms that concentrate on other types of KTT-activities (row 1 in Table 5). The difference with respect to considerably modified products is even higher (about 65%; row 2 in Table 5). We obtained

Table 5 Comparison of active/non-active firms (REAS)

Measures of Innovation Performance	All non-active firms before matching Means	Non-active firms after matching (control group)	Active firms	Difference of means of active firms/non-active firms (column 3 to column 2)	Statistical significance (test level 5%)
"Nearest neighbour" matching method					
Sales of new products as a percentage of total sales	12.57 (0.82)	13.46 (1.27)	18.12 (1.62)	4.66 (2.19)	Yes
Sales of significantly improved or modified (already existing) products as a percentage of total sales	18.23 (1.01)	18.80 (1.57)	31.11 (2.26)	12.31 (2.88)	Yes
"Caliper" matching method					
Sales of new products as a percentage of total sales	12.57 (0.82)	13.20 (0.49)	18.12 (1.62)	4.95 (1.76)	Yes
Sales of significantly improved or modified (already existing) products as a percentage of total sales	18.23 (1.01)	20.18 (1.35)	31.11 (2.26)	10.93 (2.14)	Yes

Note: N(non-active firms) = 418; 418; N(active firms) = 132; 132; the standard deviations are found in brackets under the means; two-tailed t-test for the difference of means

Table 6 Comparison of active/non-active firms (EDUC1)

Measures of innovation performance	All non-active firms before matching	Non-active firms after matching (control group)	Active firms	Difference of means of active firms/non-active firms (column 3 to column 2)	
	Means				Statistical significance (test level 10%)
"Nearest neighbour" matching method					
Sales of new products as a percentage of total sales	13.66 (0.92)	13.23 (1.01)	13.93 (1.18)	0.70 (1.58)	No
Sales of significantly improved or modified (already existing) products as a percentage of total sales	17.88 (1.06)	14.57 (0.97)	18.96 (1.40)	4.39 (1.67)	Yes
"Caliper" matching method					
Sales of new products as a percentage of total sales	13.66 (0.92)	12.60 (0.23)	13.93 (1.18)	1.33 (1.23)	No
Sales of significantly improved or modified (already existing) products as a percentage of total sales	17.88 (1.06)	16.52 (0.21)	18.96 (1.40)	2.44 (1.40)	Yes

Note: N(non-active firms) = 303; 303; N(active firms) = 246; 246; the standard deviations are found in brackets under the means; two-tailed *t*-test for the difference of means similar results also by caliper matching (row 3 and 4 in Table 5). Thus, a stronger research orientation seems to contribute to a higher performance with respect to product innovation.

For firms utilizing primarily educational activities we find that the sales share of new products is not significantly higher than that for firms without such activities (rows 1 and 3 in Table 6). The firms exploiting education activities are better the rest of the firms in terms of significantly modified products (on average the respective sales share is about 30% higher; row 2 in Table 6).

The results for the rather few firms utilizing consulting activities or activities related to technical infrastructure show no discernible differences of innovation performance in comparison to other KTT-active firms (Tables 7 and 8).

7 Summary and conclusions

This study investigated the impacts of a palette of Knowledge and Technology Transfer (KTT) activities (educational and research activities, activities related with technical infrastructure, and consulting) on two innovation indicators (a) in the framework of an innovation equation with variables for four specific forms of KTT activities as additional determinants of innovation and (b) based on a matched-pairs analysis for four forms of KTT activities.

In sum, KTT activities with research institution and/or institutions of higher education seem to improve considerably the innovation performance of firms both in terms of sales of new and considerably modified products, whereas the two effects are of comparable magnitude. This is a first important result, which seems to be quite robust across methods (see row 1 in Table 9).

Partly this is also the case for educational activities (see row 2 in Table 9). We found empirical support for a better performance based on such activities for all used methods only with respect to the sales shares of modified products. For new products we obtained evidence for a significantly higher performance only for the innovation equation but not for the two matching methods. Thus, this result is not as robust as that for research activities.

No impact could be found for activities related mainly to the consulting (row 3 in Table 9). This is also a quite robust result across all methods used in this study. According to the results of the matching methods, firms utilizing primarily the university technical infrastructure did not differ from structural similar firms with other forms of KTT activities in any type of innovation activities. This result is confirmed only partly, namely with respect to sales share of significantly improved products, by the results of the innovation equations; with respect to sales share of new products we found a positive effect in the respective innovation equation which is in contradiction to the statistically insignificant effect according to the matching methods.

New elements of the analysis are: (a) the differentiated measurement of KTT activities covering 19 different single forms of KTT activities that were grouped to four categories; (b) the use of alternative methods for estimating the impact of KTT activities on innovation performance (innovation equations; matched-pairs analysis); (c) the wide coverage of industries and firm size classes. The main drawback of the study is the lack of data for more than one point of time that does not allow confirming the cross-sectional findings in a longitudinal framework. We hope to be able to offer some remedy for this problem in the near future.

Table 7 Comparison of active/non-active firms (CONS)

Measures of Innovation Performance	All non-active firms before matching	Non-active firms after matching (control group)	Active firms	Difference of means of active firms/non-active firms (column 3to column 2)	
	Means				Statistical significance (test level 5%)
"Nearest neighbour" matching method					
Sales of new products as a percentage of total sales	13.15 (0.76)	15.25 (1.43)	16.35 (2.06)	1.10 (2.61)	No
Sales of significantly improved or modified (already existing) products as a percentage of total sales	18.12 (0.95)	19.82 (2.00)	19.19 (2.04)	–0.63 (2.97)	No
"Caliper" matching method					
Sales of new products as a percentage of total sales	13.15 (0.76)	13.32 (0.27)	16.35 (2.06)	3.03 (2.05)	No
Sales of significantly improved or modified (already existing) products as a percentage of total sales	18.12 (0.95)	20.22 (0.68)	19.19 (2.04)	–1.03 (2.13)	No

Note: N(non-active firms) = 443; 443; N(active firms) = 107; 107; the standard deviations are found in brackets under the means; two-tailed *t*-test for the difference of means

Table 8 Comparison of active/non-active firms (INFR)

Measures of Innovation Performance	All non-active firms before matching	Non-active firms after matching (control group)	Active firms	Difference of means of active firms/non-active firms (column 3 to column 2)	
	Means				Statistical significance (test level 5%)
"Nearest neighbour" matching method					
Sales of new products as a percentage of total sales	12.96 (0.80)	14.74 (1.65)	16.89 (1.76)	2.15 (2.51)	No
Sales of significantly improved or modified (already existing) products as a percentage of total sales	18.10 (0.98)	23.60 (2.30)	19.34 (1.78)	–4.26 (2.94)	No
"Caliper" matching method					
Sales of new products as a percentage of total sales	12.96 (0.80)	14.17 (0.26)	16.89 (1.76)	2.72 (1.86)	No
Sales of significantly improved or modified (already existing) products as a percentage of total sales	18.10 (0.98)	20.36 (0.40)	19.34 (1.78)	–1.02 (1.85)	No

Note: N(non-active firms) = 434; 434; N(active firms) = 115; 115; the standard deviations are found in brackets under the means; two-tailed t-test for the difference of means

Table 9 Summary of results

	Innovation equations		Matching methods			
			Near neighbour		Caliper	
	LNEWS	LIMP	LNEWS	LIMP	LNEWS	LIMP
REAS	+	+	+	+	+	+
EDUC	+	+	ns	+	ns	+
CONS	ns	ns	ns	ns	ns	ns
INFR	+	ns	ns	ns	ns	ns

Note: + : Statistically significant positive coefficient of the respective KTT variable (innovation equation); statistically positive difference of the means of active and non-active firms (matching methods) (10% test level); ns: statistically insignificant (10% test level)

Acknowledgements This study was financially supported by the ETH-Board. Useful comments and suggestions of the participants of the Annual Conference of the Swiss Association for Economics and Statistics, Lugano, Switzerland, March 9–10 2006 are gratefully acknowledged.

Appendix

Table A.1 Composition of the dataset of KTT-active firms by industry, firm size

	N	Percentage of the total
Industry		
Food, beverage	34	5.1
Textiles	9	1.3
Clothing, leather	0	0.0
Wood processing	9	1.3
Paper	9	1.3
Printing	17	2.5
Chemicals	37	5.5
Plastics, rubber	13	1.9
Glass, stone, clay	13	1.9
Metal	9	1.3
Metal working	37	5.5
Machinery	117	17.5
Electrical machinery	33	4.9
Electronics, instruments	67	10.1
Watches	6	0.9
Vehicles	9	1.3
Other manufacturing	12	1.8
Energy, water	16	2.4
Construction	32	4.8
Wholesale trade	35	5.2
Transport	21	3.1

Table A.1 continued

	N	Percentage of the total
Banks, insurances	35	5.2
Computer services	28	4.2
Business services	67	10.1
Telecommunication	6	0.9
Firm size		
5–19 employees	79	11.8
20–49 employees	103	15.4
50–99 employees	125	18.5
100–199 employees	128	19.1
200–499 employees	144	21.4
500–999 employees	52	7.8
>1,000 employees	40	6.0
Total	671	100.0

Table A.2 Probit estimates of the instrument equations for EDUC, REAS, CONS and INFR respectively

Explanatory variables	EDUC[a]	REAS[b]	CONS[c]	INFR[d]
LEXP[e]	–0.025 (0.057)	0.177** (0.071)	–0.009 (0.064)	0.199*** (0.074)
LAGE[f]	–0.066 (0.108)	–0.154 (0.124)	–0.044 (0.119)	–0.070 (0.125)
Motives[g]				
MOTIVE1 Access to human capital (“tacit knowledge”)	0.155 (0.107)	0.372*** (0.117)	0.414** (0.112)	0.184 (0.117)
MOTIVE2 Access to research outcomes (“codified knowledge”)	0.531*** (0.119)	1.188*** (0.136)	0.484*** (0.115)	0.603*** (0.119)
MOTIVE3 Financial motives	0.390*** (0.116)	0.595*** (0.116)	0.316*** (0.109)	0.656*** (0.116)
MOTIVE4 Institutional, organizational motives	1.028*** (0.111)	0.155 (0.115)	0.532*** (0.110)	0.170 (0.111)
Obstacles[h]				
OBSTACLE1 Lack of information	0.137 (0.109)	–0.144 (0.118)	–0.162 (0.119)	0.027 (0.120)
OBSTACLE2 Firm deficiencies	0.192* (0.116)	0.115 (0.127)	0.005 (0.117)	0.009 (0.122)
OBSTACLE3 Deficiencies of science institutions	0.054 (0.104)	–0.248** (0.126)	0.153 (0.121)	–0.226* (0.136)
OBSTACLE4 Costs, risks	0.007 (0.108)	0.166 (0.131)	–0.336*** (0.130)	0.154 (0.124)
OBSTACLE5 Organizational/institutional obstacles	–0.344*** (0.109)	–0.069 (0.126)	–0.276** (0.120)	–0.088 (0.117)
Region				
Lake of Geneva	0.462 (0.890)	0.217 (0.900)	–0.326 (0.869)	–1.144 (0.858)
Espace-midland	0.213 (0.844)	–0.074 (0.845)	–0.855 (0.823)	–0.958 (0.787)
Northwestern Switzerland	0.541 (0.858)	–0.070 (0.857)	–0.314 (0.823)	–1.034 (0.804)
Zurich	0.324 (0.848)	0.120 (0.852)	–0.567 (0.826)	–1.350* (0.808)
Eastern Switzerland	0.287 (0.843)	–0.474 (0.845)	–0.299 (0.813)	–0.965 (0.787)
Central Switzerland	0.204 (0.887)	–0.437 (0.919)	–0.211 (0.867)	–1.231 (0.863)
Constant	0.689 (0.934)	–1.420 (0.970)	–0.861 (0.930)	–1.081 (0.927)

Table A.2 continued

Explanatory variables	EDUC[a]	REAS[b]	CONS[c]	INFR[d]
N	644	644	644	644
McFaddenR^2	0.339	0.393	0.157	0.257
LR statistic (χ^2)	182	194***	66***	112***
% concordant	81	84	71	78

Note: [a] EDUC: 1: firms reporting 4 or 5 on a five-point Likert scale with respect to at least one out of nine single forms of educational activities (see Table 2); 0: all other KTT-active firms); [b] REAS: 1: firms reporting 4 or 5 on a five-point Likert scale with respect to at least one out of three single forms of research activities (see Table 2); 0: all other KTT-active firms); [c] CONS: 1: firms reporting 4 or 5 on a five-point Likert scale with respect to at least one out of two single forms of consulting activities (see Table 2); 0: all other KTT-active firms); [d] 1: firms reporting 4 or 5 on a five-point Likert scale with respect to at least one out of two single forms of technical infrastructure-oriented activities (see Table 2); 0: all other KTT-active firms); [e] LEXP: logarithm of exports as a share of sales; [f] LAGE: logarithm of firm age; [g] motives: factor values of a four-factor solution of a principal component factor analysis of the original 20 variables for single motives for KTT, which were measured on a five-point Likert scale (1: "not important"; 5: "very important"); [h] impediments: factor values of a five-factor solution of a principal component factor analysis of the original 26 variables for single impediments of KTT, which were measured at a five-point Likert scale (1: "not important"; 5: "very important"); dummies for the geographical region; reference region: Ticino; ***, **, * denote statistical significance at the 1, 5 and 10% test level

Table A.3 Propensity to research activities (REAS yes/no); educational activities (EDUC1 yes/no); consulting activities (CONS yes/no); activities related to technical infrastructure (INFR Yes/No)

Firm characteristics	EDUC1[a] (probit)	REAS[b] (probit)	CONS[c] (probit)	INFR[d] (probit)
LQUAL[e]		0.262 (0.086)		
LCI[f]				
LEXP[g]		0.135 (0.044)		0.125 (0.038)
LAGE[h]				
FOREIGN[i]	–0.301(0.135)			
Impediments[j]				
OBSTACLE1 Lack of information				
OBSTACLE2 Firm deficiencies	–0.142 (0.057)			
OBSTACLE3 Deficiencies of science institutions				
OBSTACLE4 Costs, risks		0.161 (0.074)	–0.164 (0.070)	
OBSTACLE5 Organizational/institutional obstacles			–0.162 (0.068)	
Motives[k]				
MOTIVE1 Access to human capital (“tacit knowledge”)	0.404 (0.055)		0.245 (0.063)	
MOTIVE2 Access to research outcomes (“codified knowledge”)	0.217 (0.054)	0.700 (0.075)	0.251 (0.063)	0.342 (0.064)
MOTIVE3 Financial motives		0.260 (0.066)	0.173 (0.062)	0.405 (0.062)
MOTIVE4 Organizational/institutional motives		0.313 (0.062)	0.299 (0.060)	
IND_1[l]				
IND_2[m]			0.454 (0.180)	
IND_3[n]		–0.562 (0.171)	0.295 (0.145)	
IND_4[o]		–0.539 (0.211)		

Table A.3 continued

Firm characteristics	EDUC1[a] (probit)	REAS[b] (probit)	CONS[c] (probit)	INFR[d] (probit)
IND_5[p]			0.623 (0.298)	
DL_1[q]				
DL_2[r]				
Firm size				
20–49 Employees				
50–99 Employees				
100–199 Employees	–0.298 (0.131)	–0.652 (0.180)	–0.365 (0.163)	–0.355 (0.161)
200–499 Employees				
500–999 Employees				
1,000 and more employees				
Region				
Lake of Geneva				
Espace-midland			–0.311 (0.155)	
Northwestern Switzerland				
Eastern Switzerland				
Central Switzerland				
Ticino				
Const.		–1.846 (0.299)	–0.968 (0.096)	–1.292 (0.132)

Table A.3 continued

Firm characteristics	EDUC1[a] (probit)	REAS[b] (probit)	CONS[c] (probit)	INFR[d] (probit)
N	635	635	635	635
Adjusted McFadden R^2	0.087	0.287	0.084	0.153
LR statistic (χ^2)	86***	217***	74***	103***
% concordant	71	86	74	77

Note: [a] EDUC1 (1: firms reporting 4 or 5 on a five-point Likert scale with respect to at least one out of nine single forms of educational activities *and* taking the value 0 for the variable REAS; 0: all other KTT-active firms); [b] REAS: 1: firms reporting 4 or 5 on a five-point Likert scale with respect to at least one out of three single forms of research activities (see Table 2); 0: all other KTT-active firms); [c] CONS: firms reporting 4 or 5 on a five-point Likert scale with respect to at least one out of two single forms of consulting activities (see Table 2); 0: all other KTT-active firms); [d] INFR: firms reporting 4 or 5 on a five-point Likert scale with respect to at least one out of two single forms of activities related to technical infrastructure (see Table 2); 0: all other KTT-active firms); [e] LQUAL: logarithm of the share of employees with tertiary-level vocational education 2004 (universities, universities of applied sciences, other business and technical schools at tertiary level); [f] LCI: logarithm of gross investment per employee 2004; [g] LEXP: logarithm of exports as a share of sales; [h] LAGE: logarithm of firm age; [i] FOREIGN: dummy variable for foreign firms; [j] impediments (OBSTACLE1–OBSTACLE5): factor values of a five-factor solution of a principal component factor analysis of the original 26 variables for single impediments of KTT, which were measured at a five-point Likert scale (1: "not important"; 5: "very important"); [k] motives (MOTIVE1 to MOTIVE4): factor values of a four-factor solution of a principal component factor analysis of the original 20 variables for single motives for KTT, which were measured on a five-point Likert scale (1: "not important"; 5: "very important");[l] dummy variable for: food and beverage, textiles, clothing and leather, wood processing; [m] dummy variable for: paper, printing, chemicals, plastics and rubber, glass, stone and clay; [n] dummy variable for: metal, metal working, machinery, electrical machinery; [o] dummy variable for: electronics and instruments, watches, vehicles; [p] dummy variable for: other manufacturing, energy and water; [q] dummy variable for: wholesale trade, transportation, banking and insurance; [r] dummy variable for: computer services, business services, telecommunication; reference industry: construction; 6 dummy variables for firm size; 6 dummy variables for geographical region; reference firm size class: 5–19 employees; reference region: Ticino. Only the coefficients are shown which were statistically significant at the 5% test level after a backward elimination of other variables

Table A.4 Descriptive statistics of the variables of the innovation equations

	Mean	Standard deviation
LNEWS	1.753	1.360
LIMPS	1.957	1.515
LQUAL	3.027	0.846
LCI	8.994	1.334
FOREIGN	0.202	0.402
REAS	0.231	0.422
EDUC	0.648	0.478
CONS	0.187	0.390
INFR	0.202	0.402

Table A.5 Correlation matrix of the variables of the innovation equations

	LQUAL	LCI	FOREIGN
LCI	–0.022		
FOREIGN	–0.094	0.041	
REAS	–0.135	–0.023	–0.029
EDUC	–0.147	–0.027	0.072
CONS	–0.065	–0.007	–0.033
INFR	0.000	0.020	–0.030

References

Adams, J. D., Chiang, E. P., & Jensen, J. L. (2003). The Influence of Federal Laboratory R&D on Industrial Research. *Review of Economics and Statistics, 85*(4), 1003–1020.

Arvanitis, S. (1997). The impact of firm size on innovative activity. An empirical analysis based on Swiss firm data. *Small Business Economics, 9*(6), 473–490.

Arvanitis, S., & Hollenstein, H. (1996). Industrial innovation in Switzerland: A model-based analysis with survey data. In A. Kleinknecht (Ed.), *Determinants of innovation. The message from new indicators*. London: Macmillan.

Arvanitis, S., Kubli, U., & Woerter, M. (2005). Determinants of knowledge and technology transfer activities between firms and universities in Switzerland: An analysis based on firm data', KOF working paper no. 115, Zurich (http://www.kof.ethz.ch/pdf/wp_117.pdf).

Barney, J., Wright, M., Ketchen, D. J. (2001). The resource-based view of the firm: Ten years after 1991. *Journal of Management 27*, 625–641.

Becker, W. (2003). Evaluation of the role of universities in the innovation process, Volkswirtschaftliche Diskussionsreihe Beitrag Nr. 241, Institut für Volkswirtschaftslehre Universität Augsburg, Augsburg.

Beise, M., & Stahl, H. (1999). Public research and industrial innovations in Germany. *Research Policy 28*, 397–422.

Bönte, W. (2004). Spillovers from publicly financed business R&D: Some empirical evidence from Germany. *Research Policy, 33*, 1635–1655.

Bozeman, B. (2000). Technology transfer and public policy: A review of research and theory. *Research Policy, 29*, 627–655.

Fritsch, M., & Franke, G. (2004). Innovation, regional knowledge spillovers and R&D co-operation. *Research Policy, 33*, 245–255.

Georghiou, L., & Roessner, D. (2000). Evaluating technology programmes: Tools and methods. *Research Policy, 29*, 657–678.

Guellec, D., & van Pottelsberghe de la Potterie B. (2003). The impact of public R&D expenditure on business R&D. *Economics of Innovation and New Technology, 12*(3), 225–243.

Hall, B., & van Reenen, J. (2000). How effective are fiscal incentives for R&D? A review of the evidence. *Research Policy, 29*, 449–469.

Hall, B. H., Link, A. N., & Scott, J. T. (2003). Universities as research partners. *Review of Economics and Statistics, 85*(2), 485–491.

Heckman, J., Ichimura, H., Smith, J., & Todd, P. (1998). Characterizing selection bias using experimental data. *Econometrica, 66*(5), 1017–1098.

Kaufmann, A., & Tödtling, F. (2001). Science-industry interaction in the process of innovation: The importance of boundary-crossing between systems. *Research Policy, 30*, 791–804.

Klette, T. J., Moen, J., & Griliches, Z. (2000). Do subsidies to commercial R&D reduce market failures? Microeconometric evaluation studies. *Research Policy, 29*, 471–495.

Klevorick, A. K., Levin, R. C., Nelson, R. R., & Winter, S. G. (1995). On the sources and significance of interindustry differences in technological opportunities. *Research Policy, 24*, 185–205.

Lööf, H., & Broström, A. A. (2005) Does knowledge diffusion between university and industry increase innovativeness? Working paper presented at the world bank workshop in Cambridge, September.

Mansfield, E. (1991). Academic research and industrial innovation. *Research Policy, 20*, 1–12.

Mansfield, E. (1998). Academic research and industrial innovation: An update of empirical findings. *Research Policy, 26*, 773–776.

Monjon, S., & Waelbroeck, P. (2003) Assessing spillovers from universities to firms: Evidence from French firm-level data. *International Journal of Industrial Organization, 21*, 1255–1270.

Nelson, R. R. (1986) Institutions supporting technical advance in industry. *American Economic Review, Papers & Proceedings, 76*(2), 186–189.

OECD (1999). Special isssue on public/private partnerships in STI review no. 23.

OECD (2002). *Benchmarking industry-science relationships*. Paris: OECD.

OECD (2003). *Turning science into business, patenting and licensing at public research organizations*. Paris: OECD.

Rosenbaum, B. R., & Rubin, D. B. (1983). The central role of the propensity score in observational studies for causal effects. *Biometrika, 70*, 41–55.

Zinkl, W., & Huber, H. (2003). *Strategie für den Wissens- und Technologietransfer an den Hochschulen in der Schweiz*. Basel: Mandat im Auftrag der Schweizerischen Universitätskonferenz SUK, Hauptbericht: Strategie und Politik im WTT.